THE THIRLMERE WATER SCHEME OF THE MANCHESTER CORPORATION

A/6

(R 9521)

MANCHESTER

CORPORATION WATER WORKS.

AREA AND CAPACITY

OF

RESERVOIRS.

1884.

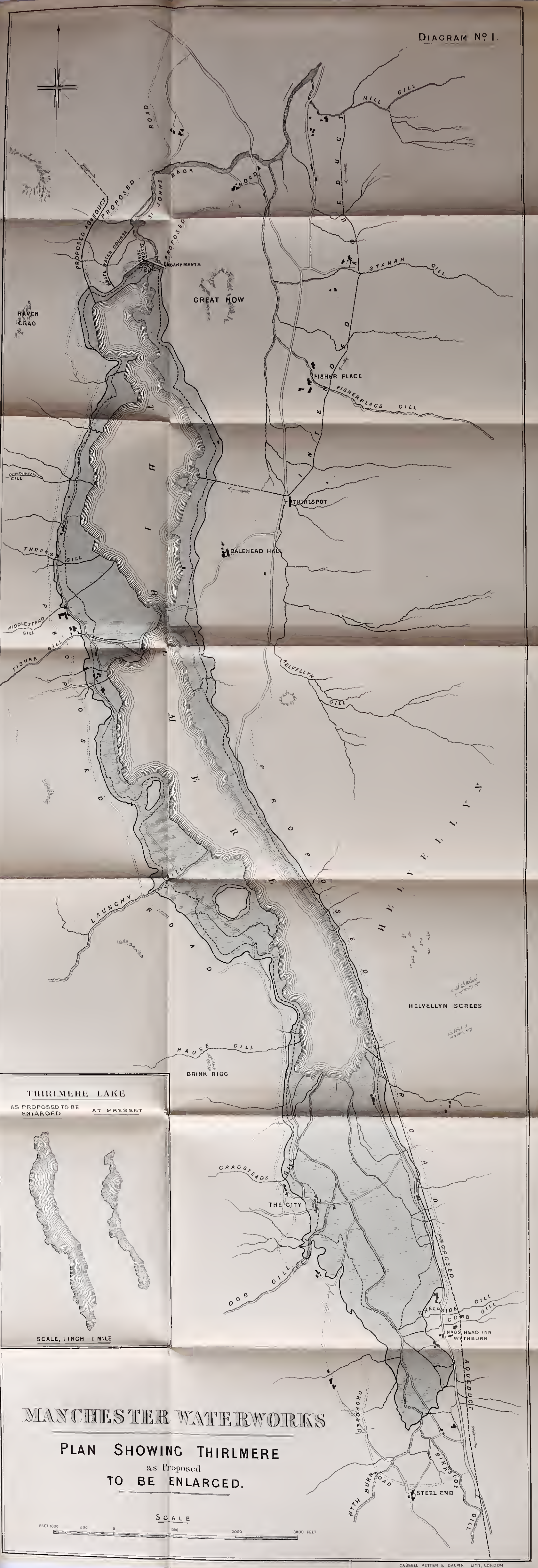


DIAGRAM No 1.
MILL GILL
AQUEDUCT
ROAD
ST JOHNS BECK
PROPOSED
PROPOSED AQUEDUCT
WASTE WATER COURSE
DISCHARGE TUNNEL
EMBANKMENTS
GREAT HOW
STANAH GILL
RAVEN CRAG
FISHER PLACE
FISHERPLACE GILL
INTENDED
THIRLSPOT
DALEHEAD HALL
THRANG GILL
MIDDLESTEAD GILL
FISHER GILL
THIRLMERE
HELVELLYN GILL
PROPOSED ROAD
HELVELLYN
LAUNCHY GILL
HELVELLYN SCREES
HAUSE GILL
BRINK RIGG
THIRLMERE LAKE
AS PROPOSED TO BE ENLARGED
AT PRESENT
SCALE, 1 INCH = 1 MILE
CRAGSTEADS GILL
THE CITY
DOB GILL
WHELPSIDE GILL
COMB GILL
NAGS HEAD INN WYTHBURN
STEEL END
BIRKSIDE GILL
WYTH BURN
MANCHESTER WATERWORKS
PLAN SHOWING THIRLMERE
as Proposed
TO BE ENLARGED.
SCALE
FEET 1000
500
0
1000
2000
3000 FEET
CASSELL PETTER & GALPIN LITH. LONDON

MANCHESTER CORPORATION WATERWORKS, RESERVOIRS AND MAINS.

OCTOBER 1883.

Sir Joseph Heron, Knt. Town Clerk.
J.F. Bateman, Esq. C.E. F.R.S. Engineer

Mr T.H.G. Berrey, Assoc. Inst. C.E.
General Outdoor Superintendent

NAME OF RESERVOIR	AREA OF RESERVOIR	CAPACITY OF RESERVOIR	DEPTH OF RESERVOIR
	ACRES	GALLONS	FEET IN
Woodhead	135	1,181,000,000	71
Torside	160	1,474,000,000	84
Rhodes Wood	54	500,000,000	68
Vale House	63	343,000,000	40
Bottoms	50	407,000,000	48
Arnfield	39	209,000,000	52
Hollingworth	13	73,000,000	52
Godley	15	61,000,000	21
Audenshaw No. 2	69	371,000,000	22 6
Denton No. 1	7	30,000,000	20
Denton No. 2	6	23,000,000	20
Gorton Upper	34	123,000,000	26
Gorton Lower	23	100,000,000	29
Prestwich	4½	20,000,000	22
	672½	4,915,000,000	
2 Reservoirs in course of construction at Audenshaw and Denton	182	1,070,000,000	
	854½	5,985,000,000	

Queenwood Mutual Improvement Society.

THE

THIRLMERE WATER SCHEME

OF THE

MANCHESTER CORPORATION,

WITH A FEW REMARKS ON THE LONGDENDALE WORKS, AND WATER-SUPPLY GENERALLY.

LECTURE

BY

JAMES MANSERGH, M. INST. C.E., F.G.S.,

DELIVERED AT QUEENWOOD COLLEGE, HANTS,

On Wednesday Evening, April 10th, 1878.

LONDON:
E. & F. N. SPON, 46, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
1878.

QUEENWOOD

MUTUAL IMPROVEMENT SOCIETY.

THE THIRLMERE WATER SCHEME.

Lecture delivered on Wednesday Evening, April 10th, 1878, by

JAMES MANSERGH, M. INST. C.E., F.G.S.

THE scheme for supplying Manchester and its suburbs with water from one of the Cumberland lakes has attracted an unusual amount of attention from the public, partly on account of its inherent magnitude, but principally because of the fierce opposition which has been stirred up against it by the Thirlmere Defence Association.

This association has printed and distributed a statement of the case, commencing as follows:—

"The Corporation of Manchester has decided to apply to Parliament, in the Session of 1878, for power to convert one of the most beautiful of the English lakes into a reservoir."

"It is almost a trite remark that the one mountain region in England is in a very high sense the property of all Englishmen; any injury to that beauty in which its value consists is a greater and more irreparable loss to the nation, as a whole, than it is to the landowners in the district. To the nation it is a gift coming direct from the hand of God, and if this gift be marred by men incapable of appreciating its value, no effort of human power or skill can ever restore what has been lost. All who value an inheritance so precious should unite in jealously guarding it from attacks destructive of its charm and power, from whomsoever they may come."

"It is quite clear, from the statements already put forth by the Manchester engineers, that the proposed works at Thirlmere will seriously and, indeed, disastrously affect the beauty of the lake and valley, whilst no real necessity can be shown for such a sacrifice on sanitary or economic grounds."

"In view of these facts, an association has been formed, principally consisting, as yet, of gentlemen living in the neighbourhood, who have resolved to offer a vigorous opposition to the project. They feel that from their local position, and intimate knowledge of the district, they are called upon to take this foremost place, but that the battle can only be won by a combination of all whose interests are really affected."

Quotations from this statement have largely appeared in the London and provincial (especially the north-country) newspapers, and in some of these the intended works have been described in a manner so erroneous as to be utterly misleading and in some instances alarming.

Having been retained by the Corporation of Manchester to support their case before the Parliamentary committees, I have had the opportunity of examining in detail the plans of the engineer, Mr. John Frederick Bateman, F.R.S., President of the Institution of Civil Engineers, and of considering on the spot the general effect of the works upon the lake and its surroundings.

This investigation has necessarily proved more interesting to me than the usual run of professional engagements, and it struck me, on receiving a Report of the Proceedings of your Society from your worthy President, that a short statement on the subject might possibly form the subject of a fairly interesting and instructive paper, to be read at one of your meetings.

Water-Supply generally.

Before describing the Thirlmere scheme particularly, I have thought it would be as well to go generally into the subject of water-supply to towns, and to refer especially to the existing works of the Manchester Corporation; but these remarks have unavoidably been put together very hurriedly, and must be taken as merely indicating the principal points, and not dealing fully and exhaustively with the subject. I must therefore crave your indulgence for the imperfections.

Source.

The original source of all water-supply is the ocean. Clouds are formed by evaporation from its surface, and these are swept over to the land by the wind. In England the prevailing wind is from the south-west, and brings the rain-clouds from the Atlantic. These discharge their contents, after condensation, as they pass over the country, in varying quantities over different districts in proportion generally to the elevation of those districts. Thus the greatest rainfall is in the mountainous counties on the west coast of Scotland, in Cumberland, Lancashire, Wales, and Cornwall. Along the south coast, for a distance of twenty or thirty miles inland, the rainfall is pretty uniform, but further to the north the amount of rain steadily diminishes towards the east.

The rain falling upon the land is ultimately again discharged into the sea, but the time occupied in its passage is affected in several ways.

In the Cumberland Lake District, for example, it falls upon the bare and almost impervious rocks of the early geological formations, and runs rapidly down the precipitous slopes of the mountains into the lakes and rivers, and so on into the Solway Firth or Irish Sea.

In such a country there are comparatively few springs, but there are many streams which are at some times roaring torrents and at others almost dry.

Here very little of the rainfall is absorbed into the ground, because, first, the slope of the surface is too steep, and, secondly, the rocks are so close, compact, and fissureless as to admit it with great difficulty.

In a chalk, arenaceous, or oolitic district, on the contrary, a great proportion of the rainfall percolates rapidly into the ground, and there are few streams on the surface, especially on the higher lands.

Such streams as do exist are at low levels, and are fed by springs.

For the purpose of supplying towns with water, works have therefore to be designed on different principles in accordance with the conditions which prevail in different localities.

Gravitation Works, Pumping Works.

These works are, broadly speaking, of two kinds, known respectively as gravitation works and pumping works.

In the first, the water is collected at such an elevation above the town to be supplied as will admit of its reaching the tops of the highest buildings by natural gravitation.

Such works are to be found in large numbers in the north of England, especially in Lancashire and Yorkshire, the water being obtained from the Pennine and other mountain ranges.

Gravitation Works.

Gravitation works may be again subdivided into two kinds—one, where the water is entirely that of springs, such as are found in the Millstone Grit (of which the Lancaster works are a good example); and the other—and by far the more common—in which flood waters are impounded in artificial reservoirs.

Pumping Works.

Pumping works may in like manner be divided into two kinds:—1st. Where the water is pumped from rivers; and 2nd. Where the water is pumped from wells.

London is an example of the first kind; *Queenwood* is an example of the second.

In both cases, power is required to lift the water to a sufficient elevation.

London Supply.

London is supplied principally by eight large companies, seven of which take their water from the rivers Thames or Lea.

By powerful steam machinery these companies force about 120 million gallons of water a day either over stand-pipes or into elevated service reservoirs, whence it gravitates through the mains and services of the several districts into the houses of the consumers.

Water thus obtained from a river like the Thames is not the most desirable water for the supply of a large population, for several reasons.

1st. Because the Thames is the natural main-drain for 2,340,000 acres, a great part being highly cultivated and manured land, the washings from which are carried into it.

2nd. There are situated upon it and its tributaries many large and increasing towns, whose sewage, in a more or less crude state, is discharged into it.

3rd. After heavy rain the river comes down, sometimes for many days together, in an exceedingly turbid condition.

This has entailed the construction of immense subsiding ponds, in which the water is allowed to come almost to a state of rest, in order that the muddy particles held in suspension may subside before the water is turned on to the filter-beds.

4th. No amount of subsidence, nor mere mechanical filtration, however perfect, can be trusted to remove from the water its organic impurities, including what are known as the "germs" of disease.

In ordinary times, and when the filtration is thoroughly well done, the water as delivered in London is fairly wholesome, but it is contended by many scientific men of high position—notably by Dr. Frankland (who at one time lectured regularly from this table)—that if an epidemic of cholera or typhoid prevailed at Windsor, or any of the towns above the intake, it would be exceedingly dangerous to drink the water pumped into London from the Thames above Teddington Weir.

Pumping schemes, where large rivers are the source of supply, are year by year falling more and more into disrepute, on account of the suspicion which thus naturally attaches to the water.

On the other hand, where proper precautions are taken for the prevention of percolation from the surface down to a sufficient depth, supplies like that of Queenwood are to be commended.

In the present Session of Parliament a scheme is to be considered which provides for the obtaining of a supplemental supply of water for London from the chalk, in order that the use of the polluted water of the Thames for drinking and culinary purposes may be avoided.

Ancient Waterworks.

The great waterworks of ancient times were principally gravitation works; for until the invention of the steam-engine it was impossible to raise water artificially in large quantities to the heights to which it is now lifted for town supply.

Wells were no doubt constructed in antediluvian ages, but most of these would probably be very shallow.

One of the ancient proverbs of the Chinese is, "Dig a well before you are thirsty;" and the numerous deep artesian wells found in their country give evidence of the proverb having been duly regarded. Wells were very numerous in ancient Greece: Vitruvius, Plutarch, Pliny, and Herodotus make mention of them. "Previous

to the time of Appius Claudius Cæsar, the city of Rome received its supply chiefly from wells. The disinterment of the cities of Herculaneum and Pompeii has proved the existence of many public wells in ancient Italy. At Pompeii, a very fine well, 116 feet in depth, was discovered near the gate of the Pantheon."*

The Romans constructed many magnificent aqueducts, and it is believed that when the population of Rome was one million, nearly three times as much water was delivered into the city daily as is now supplied to London.

The remains of several of these aqueducts I have seen; and a few years ago I spent several weeks in investigating a scheme for providing to the city of Naples a supply of water from a source, at a distance of over forty miles, which had been utilised in the time of Claudius.

The water was brought from a series of magnificent springs forming the river Orciouli, near the town of Avellino, and in its course the ancient Claudian aqueduct had been constructed in tunnels several kilometres in length, and it appeared to have a regular falling gradient of about 1 in 2,000 throughout.

"The Romans not only provided their own capital city with water, but constructed works of considerable magnitude in other countries of their dominions. In Constantinople, in Sicily, Greece, Spain, and France, we find the remains of their gigantic conduits; and although many centuries have elapsed since they were constructed, several of them still afford those advantages for which they were originally intended."

Most of the Roman aqueducts were formed either in tunnel or on elevated arches, often in two or more tiers one above another. One of the best typical examples is the "Pont-du-Gard," forming part of a conduit which supplied the town of Nismes with water from the sources of the Airan, which rose near St. Quentin, and the Ure, near Uzès. This noble structure is, perhaps, one of the grandest monuments which the Romans have left in France or any other country. "It consists of three tiers of arches, the lowest, of six arches, supporting eleven of equal span in the centre tier, surmounted by thirty-five of smaller size; the whole is in a simple style of architecture, destitute of ornament. It is by its magnitude, and the skilful fittings of its enormous blocks, that it makes an

* HUMBER. On Water Supply of Cities and Towns.

impression on the mind. It is the more striking from the utter solitude in which it stands—a rocky valley partly covered with brushwood and greensward, with scarcely a human habitation in sight. After the lapse of sixteen centuries, this colossal monument still spans the valley, joining hill to hill in a nearly perfect state, only the upper part at the north extremity being broken away. The highest range of arches carries a covered canal about five feet high and two feet wide, shaped in section like the letter U. It is covered with stone slabs, along which it is possible to walk from one end to the other, and to overlook the valley of the Gardon. The arches of the middle tier are formed of three distinct ribs or bands, apparently unconnected. The height of the 'Pont-du-Gard' is 180 feet, and the length of the highest arcade 873 feet. Its date and builder are alike lost in oblivion, but it is attributed to M. Agrippa, son-in-law of Augustus, B.C. 19. M. Genieys, formerly Engineer-in-Chief to the municipality of Paris, estimated that the quantity of water conveyed by this conduit amounted to nearly 14,000,000 gallons per day."*

The time at my disposal will not allow of my dwelling longer on these ancient hydraulic works. I have referred to them merely that you may have the opportunity of comparing them with the methods of construction adopted in modern times.

Before, however, proceeding to the description of the existing and proposed Manchester works, I would like to say a few words about the Queenwood supply.

I find in the Sixth Report of the Rivers Pollution Commission an analysis of the water taken from the well supplying the establishment. This well is situated at what in my time was known as the farm, and is sunk 169 feet into the chalk, and the water is pumped from it by a steam-engine into a tank at the top of the play-ground, from which it gravitates back to the house through pipes.

Twenty-seven years ago this tank was open (I trust it has since been covered), and one very hot day about a score of lads cooled themselves down by bathing in it. It was not a nice thing to do, but boys as a rule have strong stomachs, and did not at the time realise the impropriety of the proceeding. Unfortunately for the two who scrambled out last, at the sound of the bell, they were discovered in a half-dressed condition and had to "own up."

* HUMBER.

Very pluckily they did not tell of the others, but they both got the most awful licking I ever saw administered; and in my time I had seen and felt a good deal more of such correction than is common in these degenerate days.

Of one of these lads I have heard nothing for many years, but the other is now a highly-esteemed Member of the House of Commons.

Excepting when abnormally fouled in this improper manner, the Queenwood water is of excellent quality; but it is not such a water as is suitable for manufacturing towns where steam is largely used, and where the processes of scouring, dyeing, &c., are carried on.

For such purposes it is much too hard, by reason of the bicarbonate of lime it contains, and which it has acquired in passing through the chalk from the surface to the point at which it is picked up by the pumps.

"The amount of solid matters dissolved in water from deep wells sunk in the chalk is always large, but a very minute proportion only is organic, the remainder being innocuous to health, as it consists chiefly of chalk combined with carbonic acid."

"Chalk is an excellent filtering and cleansing material for water, and whilst it absorbs a larger proportion of the rainfall than does any other stratum, the water is again yielded to deep wells in a condition of freedom from organic matter not surpassed by the water from any other geological formation."

"The water entering the chalk is, however, almost always to some extent polluted by animal matter before it leaves the surface. The pollution is slight if the rain falls upon the grassy slopes of a chalk down; it is much more considerable when the rain soaks through highly-manured soil, and it is greatest when the chalk is cut up and honey-combed by sewers and cesspools."*

It is therefore of the utmost importance that the site of a well in the chalk intended to supply water for domestic purposes should be judiciously chosen in the first instance, and that its neighbourhood should not subsequently be fouled in any way, and especially by animal matters.

The following is the analysis of the Queenwood water, as given in the Rivers Pollution Report, and under it are a few typical samples of other descriptions of water for comparison:—

* Sixth Report, Rivers Pollution Commission.

Result of Analyses expressed in Parts per 100,000.

Water from	Total Solid Impurity.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total Combined Nitrogen.	Previous Sewage or Animal Contamination.	Chlorine.	Hardness.		
									Temporary.	Permanent.	Total.
Queenwood	29·54	·044	·005	0	·541	·546	5090	2·20	16·1	6·3	22·4
Glasgow (Loch Katrine)	3·20	·192	·008	·001	0	·009	0	·79	...	...	1·0
Lancaster (Millstone Grit)	4·58	·129	·022	·001	0	·023	0	·99	...	...	·9
Thirlmere	2·66	·194	·004	·003	·002	·008	0	·52	...	...	·7
London (West Middlesex), filtered Thames .	26·40	·125	·021	0	·155	·176	1230	1·45	...	...	19·3
Liverpool (Red Sandstone Well)	26·40	·020	·020	0	·416	·436	3840	2·68	4·0	9·6	13·6
Bath (Spring Water from the Oolite) . . .	30·76	·009	·004	0	·130	·134	980	1·46	21·8	5·4	27·2

Manchester Old Works.

Prior to 1847 Manchester was very inadequately supplied with water by the Manchester and Salford Waterworks Company; but about that time the Corporation awoke to the importance of providing for the city a better supply. They therefore came to terms with the Company for the purchase of the old works, paying them the round sum of £630,000 for little more than the old pipes.

In 1847 they applied to Parliament for powers to construct works in the Longdendale valley for the storage of the surplus waters of the river Etherow and its tributaries.

These are gravitation works of the second class (see *ante*), and were designed by Mr. Bateman, who has been continuously engaged upon them for the last thirty years, and they consist of a series of reservoirs forming steps in the valley, one above another, for a distance of about five miles. (See Diagram No. 4.)

The watershed of this Longdendale district has an area of 19,000 acres, shown by shading on Diagram No. 3.

This diagram is an outline map of the district from near Keswick, in Cumberland, to below Manchester, on a scale of 5 miles to an inch, and will again be referred to later on.

It would probably be difficult to discover in England many valleys so admirably adapted—so far as its superficial configuration is concerned—for the construction of a series of large impounding reservoirs.

Diagram No. 4 contains a plan of the five principal reservoirs, on a scale of 6 inches to a mile, and a longitudinal section of the valley on the same horizontal scale and 100 feet to an inch vertical. This plan and section explain at a glance the way in which the valley has been utilised.

From the centre of the lowest embankment, that of the Bottoms Reservoir, to the upper end of the Woodhead Reservoir, the total rise of the valley is 344 feet, and the distance is $5\frac{1}{2}$ miles, giving an average inclination of 1 in 83, or 64 feet in a mile.

I wish you to remember this when we come to talk of Thirlmere.

The following is a table giving the height of embankment, the area of the water surface when full, and the content or storage capacity, in gallons, of each of these reservoirs :—

Name of Reservoir.	Height of Bank.	Water Area.	Capacity.
	Feet.	Acres.	Gallons.
Bottoms Reservoir . .	66	50	407,000,000
Vale House	55	63	343,000,000
Rhodes Wood	75	54	500,000,000
Torside	100	160	1,474,000,000
Woodhead	90	135	1,181,000,000

Reservoir Construction.

It will perhaps be as well if I now describe shortly the mode of constructing one of these large storage reservoirs.

First of all, the most favourable site is selected by a careful examination of the valley, the desirable features being the following :—

At the spot chosen for placing the dam, or embankment, the two sides of the valley ought to converge or come together, so as to make the length of the embankment as short as possible.

Then above the dam the valley ought to widen out, the stream winding through a flat or gently rising plain between low banks, the sides of the main valley being fairly steep. The less the rise of the ground along the course of the stream, and the wider the flat of the bottom, the better, because by means of a short and not over high embankment a large quantity of water will be impounded.

Of some parts of England, the northern counties especially, there are published by the Ordnance Department, maps on a scale of 6 inches to a mile which have drawn upon them what are technically called "contour lines."

These are horizontal lines accurately levelled upon the ground, then as carefully surveyed and transferred to the plans.

Over a very large district of medium elevation, these lines are "run" 25 feet apart; that is to say, a line 500 feet above Ordnance datum is given, then above it one of 525, 550, 575, 600, and so on ; and similarly below.

By means of these contours it is much easier for any one accustomed to the plans to lay out reservoirs and other works in the office than in the field.

At a glance the eye takes in all the features of the country,

a single sheet covering 24 square miles, and you will at once understand how the work of the engineer is facilitated by these magnificent maps.

It is to be regretted that this survey is not more rapidly prosecuted and published throughout the whole country.

So far the reservoir site has been chosen with reference only to the outward and visible surface formation.

Next must be ascertained the geological fitness of the site, for upon this depends the amount of the original outlay in construction and the utility of the reservoir when finished.

It would be useless to make a large embankment across a valley if there were faults and fissures in the strata that would allow the water to escape.

There have been instances of reservoirs being abandoned because they would not hold water, especially in the "coal measures."

Then, again, the exact spot upon which the embankment is to be founded must be carefully explored, by sinking trial holes or borings all the way across the valley.

For you must understand that the bank is not simply a great mound of earth planted upon the surface soil; but it must be rooted as it were into the solid ground.

For this purpose a trench is cut right across from side to side through the alluvium which more or less is found in such situations, and is carried down until it reaches some watertight stratum, which in all probability forms the true base of the valley and is continuous throughout the whole area to be submerged in the intended reservoir.

In a "millstone grit" district like the Longdendale, the rocks are very much disturbed and dislocated, and in some of these embankments the trenches have had to be excavated to very great depths before a watertight layer of shale has been reached.

At Woodhead the cutting was between 50 and 60 feet below the bed of the brook, and as the same level had practically to be maintained right into the sides of the valley, the total extreme depth became as much as 160 feet.

Into this trench, when excavated, was filled an immense wall of blue-lias concrete, tied down into the watertight shale all across the valley, so as to complete the impervious basin forming the reservoir.

In valleys which have been overlaid thickly by glacial drift, such

as "boulder clay," ages after their original formation, the necessity of sinking a deep trench would be avoided.

If the whole area intended to be covered with water is, on examination, found to be so covered, a trench would be cut, say, 6 or 8 feet deep and filled with clay puddle, and this would be carried up like a wall to above the intended top-water level, and supported on each side by earth formed to suitable slopes.

Discharge Pipe.

Provision has, of course, to be made for drawing the water off from near the bottom of these reservoirs; for a reservoir that is always full would be of no more use than a barrel of beer which had no tap in it by which the beer could be drawn.

The use of a reservoir of this sort is, in fact, to store up the surplus water of floods and give it out again in dry seasons.

The quantity of water passing down mountain streams varies at different periods of the year in the proportion of one to many hundreds.

At some times, therefore, streams in their natural condition discharge an excessive quantity which is not only useless, but positively injurious, and at others they are feeble dribbles insufficient to turn mills, and sometimes even for ordinary riparian requirements.

By thus impounding flood waters the general utility of a stream is enhanced to those who occupy its banks, as manufacturers below; and even after their wants have been fully met, a surplus is left which can be taken away by pipes for the supply of the large centres of population.

It will thus be seen that the outlet from the reservoir must be so devised and arranged as to discharge part of the water into the river, to run down the natural channel, and the remainder into the pipes for supply to the town.

The adjustment of the proportions in which the water shall be so delivered has often been a subject of sharp contention betwixt the promoters, on the one hand, and the millowners and riparian proprietors, on the other, during the passing of Water Bills through the Parliamentary Committees of the two Houses.

When the Act for the Longdendale Works was obtained in 1847, it

was stoutly opposed by parties interested in the river Etherow, which is a stream that does not pass through Manchester, but further to the east, through the town of Stockport, and the result of that opposition was that the Corporation were obliged to apply to Parliament in the following session for powers to secure an extension of the gathering-ground area, and to construct additional reservoirs.

Compensation Water.

The quantity ultimately fixed upon for discharge into the river—technically described as "compensation" water—was something over 17,000,000 gallons a day. This quantity was afterwards reduced to 13,600,000 gallons per day by purchase from the millowners.

After delivering this quantity, the Corporation were then at liberty to take to Manchester all the rest of the water that they could obtain from the watershed by the works authorised under their several Acts.

This "compensation" water is passed into the river Etherow below the Bottoms Reservoir, and is measured by passing through suitable orifices; and the millowners are further enabled to check the quantity by means of large chambers of known capacity, into which, by means of simple apparatus, the water can be turned, and the time they take to fill accurately registered.

Discharge-Pipe.

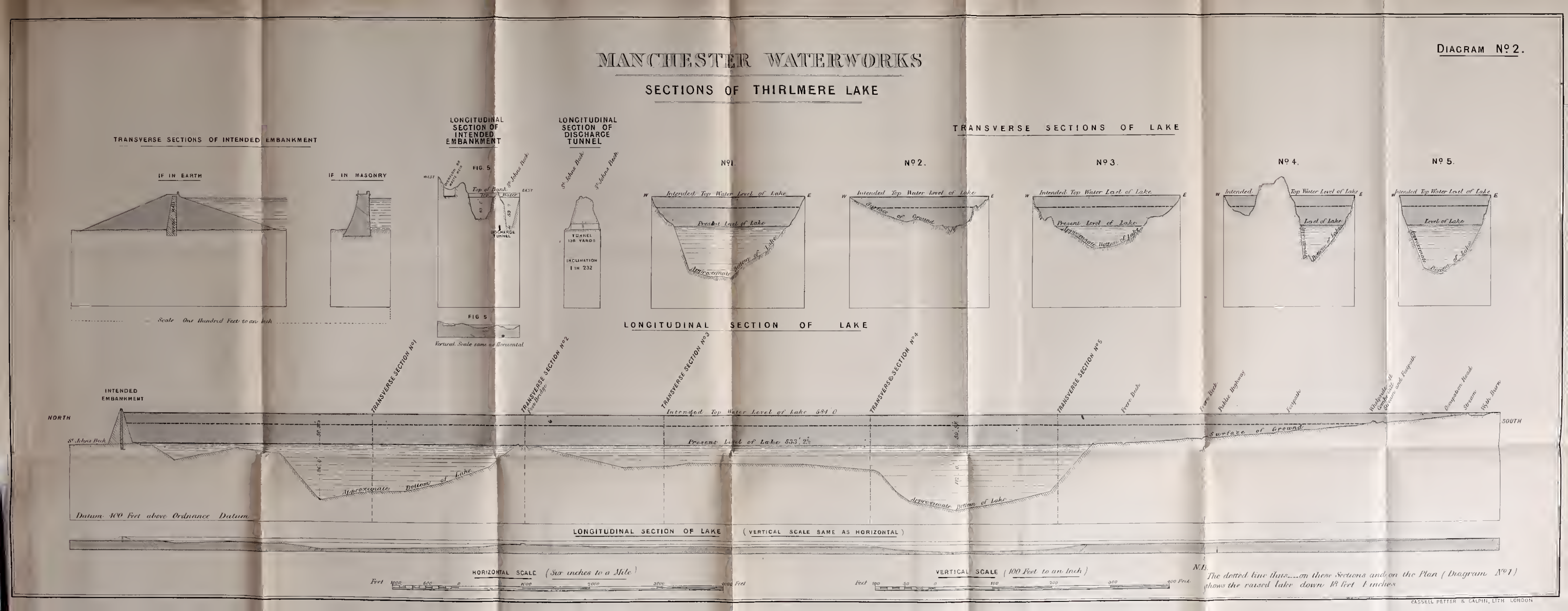
The discharge-pipe from the bottom of a reservoir is one of its most important details.

In many of the early works this pipe was laid right through the deepest part of the bank, just as a water-pipe is laid in a street, bare and unprotected.

This, no doubt, was a very faulty mode of construction, and gave rise to leakages and subsidences, and in some cases to the total failure and destruction of reservoirs.

Now the approved plan is to drive a tunnel in the solid ground round one end of the embankment, and to lay the discharge-pipes in it, passing them through a watertight "bulkhead" or "stop" in the tunnel, and commanding them by means of valves and proper gearing.

Precautions have, of course, to be taken to prevent the water,



MANCHESTER WATERWORKS
SECTIONS OF THIRLMERE LAKE
DIAGRAM Nº 2.
TRANSVERSE SECTIONS OF INTENDED EMBANKMENT
IF IN EARTH
IF IN MASONRY
Scale One Hundred Feet to an Inch
LONGITUDINAL SECTION OF INTENDED EMBANKMENT
FIG. 5
Top of Bank
DISCHARGE TUNNEL
Vertical Scale same as Horizontal
LONGITUDINAL SECTION OF DISCHARGE TUNNEL
St. Johns Beck
TUNNEL 136 YARDS
INCLINATION 1 IN 232
TRANSVERSE SECTIONS OF LAKE
Nº 1.
Nº 2.
Nº 3.
Nº 4.
Nº 5.
W
E
Intended Top Water Level of Lake
Present Level of Lake
Approximate Bottom of Lake
Surface of Ground
LONGITUDINAL SECTION OF LAKE
NORTH
SOUTH
INTENDED EMBANKMENT
TRANSVERSE SECTION Nº 1
TRANSVERSE SECTION Nº 2
TRANSVERSE SECTION Nº 3
TRANSVERSE SECTION Nº 4
TRANSVERSE SECTION Nº 5
Intended Top Water Level of Lake 584' 0
Present Level of Lake 533' 2½
Approximate Bottom of Lake
Surface of Ground
Datum 400 Feet above Ordnance Datum
Public Highway
Footpath
LONGITUDINAL SECTION OF LAKE (VERTICAL SCALE SAME AS HORIZONTAL)
HORIZONTAL SCALE (Six inches to a Mile)
VERTICAL SCALE (100 Feet to an Inch)
N.B. The dotted line thus.....on these Sections and on the Plan (Diagram Nº 1) shows the raised lake down 18 feet 1 inches
CASSELL PETTER & GALPIN, LITH. LONDON

which may be standing in the reservoir 70 or 80 feet above the outlet, from following along the outside of the tunnel, and thus escaping.

Nothing is more insidious and penetrating than water under pressure. If there is a weak place it is sure to find it out, and therefore every detail must be most thoroughly considered, and the execution of the work most rigorously supervised.

In constructing a barrier of this description across a valley, provision must necessarily be made for the passage of the stream during the time the works are going on.

Directly the puddle-wall is brought up above the level of the ground, and the erection of the supporting embankment is commenced, the water of the stream will begin to accumulate behind it, and in case of flood would overtop it and wash the earth away.

This is ordinarily prevented by using the outlet tunnel to discharge the waters of the stream during construction, and inserting the "bulkhead" or "stop" after the permanent "byewash overflow" (which I will describe presently) has been completed.

Flood-water Channel.

In other cases, however, what is known as a flood-water channel is constructed; that is, a channel commencing in the stream at what will ultimately be top-water level at the head of the reservoir, following along the hill-side with a very slight fall, and then dropping down into the stream again below the embankment.

By this means all the water in the stream above the upper end of the reservoir is diverted from the actual reservoir site, and the small quantity falling upon this limited area can be easily dealt with by pumping, or otherwise, at the embankment.

Having formed this channel, the works may be prosecuted without risk of interference or damage from the stream, and the channel may ultimately be made use of in keeping out of the reservoir turbid or discoloured water, which can be passed round it direct into the river below.

Sorting Water in Longdendale.

There are certain arrangements in connection with the Longdendale Works for the sorting of the water which there will be no time to describe in detail, but which I will just refer to in passing.

The compensation water delivered into the river is principally used for power; that is, for turning the water-wheels which actuate the machinery in the different works.

For such a purpose dirty water, or water discoloured by peat, is just as good as clean.

Hence an ingenious mode of automatically selecting waters of different qualities has been devised and erected on some of the tributary streams, the dirty water being passed into certain of the reservoirs for "compensation," and the clean water into others for "supply."

This is effected by causing the water to fall vertically over a weir, immediately below the edge of which is a channel having a narrow slit or longitudinal opening in the top.

It has been found by experience that whilst the stream is running up to or below a certain quantity it is fit to send into the "supply" reservoirs, and this quantity drops quietly over the weir into the slit, and away by the clean-water channel.

As the volume increases after rain, and the water in consequence becomes turbid and coloured, it overleaps the aperture and runs down to the "compensation" reservoirs.

Waste-Weir.

I must now complete the general description, by reverting to the waste-weir, or overflow.

Just as an outlet is necessary near the bottom of a reservoir in order to empty it, so a means of escape is required above to prevent the water rising and running over the embankment.

This overflow is usually built in masonry in the shape of a long level cill at top-water level, six or eight feet below top-bank.

Its length is determined by the area of the watershed above, and by the character of the floods common in the district. It must be made long enough to discharge the greatest quantity of water that can possibly come down when the reservoir is full, without there being the slightest risk of the water rising to top-bank level.

Bradfield Dam.

Some of you may have read an account of the bursting of the Bradfield Dam on the Sheffield Waterworks about twelve years ago,

and of the frantic attempts which were made at the last moment to blow away part of the overflow so as to lower it, and so allow the water to escape down the byewash.

In this case it is supposed either that the pressure of the water behind the bank caused it to slide on its base, which in part was smooth rock on a sharp inclination; or that the lower part of the bank had been injured by water finding its way out of or along the naked iron pipes by which the water was discharged.

Suffice it to say that some cause of this nature had led to a subsidence which diminished the margin betwixt overflow level and top-bank level; the water poured into the reservoir faster than the overflow would discharge it, and crept gradually up inch by inch until it topped the bank, when the destruction commenced, and the result was one of the most awful catastrophes that ever occurred in this country.

A fearful flood was instantly created in the already swollen river, and the resistless torrent rushed impetuously down the valley, carrying before it houses, and mills, and trees, right down to the town of Sheffield, destroying 238 lives, and property of immense value.

Flood Discharge.

The greatest quantity which I have ever heard of as having been measured on any waterworks in England as running off the ground is 450 cubic feet per second per thousand acres.

Dry Weather Flow.

The *minimum* discharge in time of excessive drought from the same watershed would probably be about one-fourth of a cubic foot per second per thousand acres, one eighteen-hundredth of the flood discharge.

So great are the extremes which have to be dealt with!

Byewash.

From the cill of the overflow the water drops into the byewash, which is generally a stepped channel of masonry leading to the river below the bank.

From this hurried and imperfect description, coupled with the

explanatory diagrams, I trust you will have obtained, at all events, a general idea of the nature of the Longdendale and similar impounding works.

I need only add that from the storage reservoirs the water is conveyed by culverts or pipes to the service reservoirs nearer Manchester, and then through the ramification of mains in the streets to all the houses within the district of supply.

The Corporation are still engaged (under Mr. Bateman's advice) in the construction of reservoirs at Denton, intended to store some water which still at times runs to waste from the Longdendale gathering ground.

When these reservoirs are completed, this watershed will be fully utilised, and will be sufficient to supply 24½ million gallons a day for the city and its suburbs, in addition to the 13⅓ millions required for compensation.

This quantity, although more than ample for present requirements, must be much augmented as time goes on, by means of new works on a new watershed.

The quantity of water now used per day in a dry year may be taken as 17 million gallons, and the demand continues to increase at the rate of something approaching a million a day per annum. In the course of 8 or 10 years, therefore, the supply from Longdendale will only just meet the requirements of the district; and, having regard to the time necessarily occupied in the execution of works, it clearly behoved the Corporation, under these circumstances, to be casting about for a new source of supply, and, not unnaturally, their attention was directed to the Lake District.

About the year 1868 Messrs. Hemans and Hassard elaborated a scheme for bringing this water to London, and more recently Mr. Bateman suggested that Liverpool and Manchester should coalesce for a similar purpose, Ulleswater being then indicated as the principal impounding reservoir.

Two years ago the special advantages of Thirlmere were pointed out by Mr. Graves, the energetic Chairman of the Water Committee—(a native of the locality)—and a thorough engineering investigation has resulted in the scheme being presented to Parliament in the present session.

It is estimated that by the time the first instalment of water can

be delivered to Manchester from Thirlmere, the 24½ millions obtainable from Longdendale will be required in a dry year.

As being responsible for the provision of water to a present population of 800,000 people,—rapidly increasing,—the Corporation are evidently, therefore, not far in advance of their duty in seeking to obtain the sanction of Parliament at once to this undertaking.

It appears to be a wise and prudent thing for them, after their past experience, to decide upon a scheme which, whilst it will not entail the immense anxiety, risk, and expenditure of time involved in the making of such a series of reservoirs as those in Longdendale, will set at rest the question of water-supply to Manchester for a great many years to come.

It is also a considerate thing with regard to smaller towns in Lancashire for Manchester to pass by intermediate watersheds available for such towns, and better adapted to their more limited wants and resources, and to incur the outlay on a hundred miles of aqueduct in order to supply itself, and to leave the nearer water for its less wealthy neighbours.

On these and other grounds Thirlmere has been selected as the source which shall supplement Longdendale in the supply of water to Manchester and its suburbs in future years.

THE THIRLMERE SCHEME.

Thirlmere is one of the least important of the Cumberland lakes.

It lies at the foot of the Helvellyn range, immediately to the west or left hand of the main road leading from Grasmere to Keswick, and for two-thirds of its length at its south end it is visible from that road.

It is almost severed in two in the middle by promontories, which approach each other from the east and west, and leave a narrow stream, over which a footpath is carried by three rude bridges.

The south end of Thirlmere is about two miles to the north of the summit of Dunmail Raise, the low pass or ridge which divides the watershed of Grasmere, Rydal, and Windermere on the south from Thirlmere, and the river Greta on the north and west.

Elevation of Fourteen Principal Lakes.

Thirlmere is the next to the highest of the fourteen principal lakes of this district, the following being their respective altitudes in feet above Ordnance datum :—

Hawes Water	695	Derwent Water	238
Thirlmere	533	Bassenthwaite	226
Ulleswater	477	Grasmere	208
Loweswater	429	Wastwater	204
Ennerdale	369	Rydal	181
Buttermere	331	Coniston	147
Crummock	321	Windermere	134

Thirlmere Area, &c.

The present area of the lake at its ordinary level is about 350 acres, and its length 2½ miles.

In times of heavy rain it rises from 6 to 8 feet above this level, but runs down very rapidly.

Its outlet is into St. John's Beck, a tributary of the Greta.

Gathering-ground Area.

The extent of gathering ground—that is, the watershed area from which the rainfall naturally runs into Thirlmere—is 7,400 acres. This rainfall is delivered into the lake by the following streams—viz., Wyth Burn, Ullscarf Gill, Dob Gill, Cragsteads Gill, Hause Gill, Launchy Gill, Fisher Gill, Middlesteads Gill, Thrang Gill, Dowthwaite Gill, Whelpside Gill, Comb Gill, and Birkside Gill.

It is intended to increase the watershed area into the lake by intercepting several other streams which now flow into the St. John's Beck *below* the lake, by means of artificial channels cut along the hill-sides and reversing the present direction of their flow.

These streams are Shoulthwaite Gill on the north-west, having a gathering-ground area of 1,020 acres, and Mill Gill, Stanah Gill, Fisherplace Gill, and Helvellyn Gill on the north-east, having an additional area of 2,500 acres.

These three areas combined bring up the total watershed into the lake to 10,920 acres, or about 17 square miles, or not much more than half the area draining into the reservoirs in the Longdendale valley. (See Diagram No. 3.)

Supply from Thirlmere.

As I have before stated, Longdendale will provide 24½ million gallons per day for the town, and 13½ millions for "compensation."

From Thirlmere it is anticipated that nearly 50,000,000 gallons per day may be obtained for "supply," in addition to 5,500,000 for "compensation."

The principal reason for this great excess in the produce of Thirlmere is, of course, the very much heavier rainfall in the Lake District; secondary reasons being a small amount of loss by evaporation and absorption, and ample storage capacity relatively to the gathering-ground area and rainfall.

On these points I had better enter into a little detail, so as to ensure their being fully understood and their importance realised.

Rain-gauge.

You are, of course, aware that the quantity of rain that falls upon any particular spot can be pretty accurately ascertained by means of an instrument called a rain-gauge.

Upon most waterworks' gathering grounds several of such gauges are fixed, and the rainfall is regularly registered, the number depending upon the area from which the water is collected.

On the Manchester Works six rain-gauges have been in operation since the year 1855.

I may mention in passing that the collection of rainfall statistics has been brought to a high state of efficiency by Mr. G. J. Symons, who during the last eighteen years has gradually organised a system of returns from over 2,000 stations in the United Kingdom. This information is of the utmost value to hydraulic engineers, and is also a matter of great interest to meteorologists and other scientific men.

In order to avoid a mass of figures, I will confine my attention to only one of the Manchester gauges—viz., the one at the Woodhead Reservoir, situated 680 feet above the sea.

The average annual rainfall for a period of twenty-three years (from 1855 to 1877) at this gauge has been 50·35 inches. The maximum, in 1866, was 64·58 inches, and the minimum, in 1855, was 40·33 inches.

Results of Rainfall.

One inch of rainfall upon one acre is equivalent to 22,622 gallons.

The average annual rainfall at Woodhead of 50 inches would therefore be 1,131,000 gallons per acre; and if this average applied to the whole 19,000 acres of watershed in the Longdendale valley, as it probably very nearly would, the total quantity of rain falling upon this area in a year would amount to 21,490,000,000 gallons, or nearly 60,000,000 gallons per day.

This must not, however, be taken as the quantity which runs off the ground in the shape of streams, and which would therefore be collectable in a lake or artificial reservoir.

Loss.

A certain proportion of the rainfall is either re-evaporated from the surface, absorbed by vegetation, or percolates into the ground.

The "evaporation" and "absorption" are, of course, so much absolute loss for waterworks purposes; the water which percolates into the ground may possibly re-appear in the shape of springs within the scope of the works, and so become available.

The amount of loss by evaporation and absorption depends upon the nature of the ground the rain falls upon. On flat, peaty moorlands it is very considerable. On steep, rocky ground, especially where the rocks are of close texture and impervious, it is comparatively small.

The amount depends also upon the character of the rainfall. Light summer showers, in otherwise dry weather, influence in a very slight degree the run of the streams, because the moisture is greedily taken up by plants or readily evaporated.

On the Manchester Works this "loss" has been measured for fourteen years, and has been found to average very nearly 10 inches, and to vary from 5·16 inches to 13·83 inches.

From the clean, steep, and rocky watershed of Thirlmere, with the atmosphere frequently saturated with moisture, the loss will doubtless be less than in the Longdendale valley, and it will probably be sufficient to estimate it at 8 inches on the average of years.

Rainfall of Lake District.

The rainfall on the lake mountains is notoriously very high, and upon the 11,000 acres draining into Thirlmere probably as great a quantity will fall as upon any similar area in the district.

The very heavy falls are, however, peculiarly local; a difference of 10 inches per annum may occur at two stations only half a mile apart.

This is caused by the special configuration of the hills and valleys.

Up to about 2,000 feet above the sea the rainfall, when not thus affected by local circumstances, increases pretty regularly in proportion to the elevation; above 2,000 feet this increase is not maintained.

Rainfall of Thirlmere Watershed.

In order to arrive at a close approximation to the facts with regard to the 11,000 acres, Mr. Bateman had six gauges erected, in March, 1877, in such situations as were calculated to give a fair mean over the whole area, and these have been observed for ten months.

They were placed in the positions indicated in the table below. The first column of figures gives the elevation of the gauge, and the second the total fall at each gauge to the end of the year or during ten months, excepting in the case of Whiteside, which was in operation during only thirteen days of March :—

Station.	Height above Ordnance datum.	Rainfall.
	Feet.	Inches.
Helvellyn	1,900	90·6
Whiteside	2,100	91·1
Ullscarf	2,100	130·5
Armboth Fells	1,655	93·4
Wythburn	585	96·4
Armboth	550	85·9

The average of these six gauges is 98 inches.

It was then found by inquiry that an old gauge at Seathwaite, a few miles distant, had registered almost exactly as much during the

ten months as the Ullscarf gauge; and it was therefore assumed that the fall at the two places was probably similar during the two months of January and February not gauged at Ullscarf, and that in fact the whole year's rainfall at the two gauges was practically the same.

Then the mean fall for the year at all the gauges was arrived at by proportion thus: As 10 months' gauging at Ullscarf is to 10 months' mean on the six gauges, so is 12 months' gauging at Ullscarf to the mean of 12 months' gauging on the six gauges; or in figures: As 130 : 98 : : 168 : 127, which is taken as the mean rainfall for the year 1877 over the whole 11,000 acres.

Then it was found, from an examination of gaugings over a long series of years in this district, that the *mean* rainfall was 20 per cent. less than that of 1877, and therefore one-fifth was deducted, bringing the 127 down to 102.

This figure may fairly be compared with the 50 inches on the Woodhead gauge, and therefore, speaking broadly, the rainfall of the Thirlmere watershed may be estimated at double that of Longdendale.

Comparison of Yield.

We are now in a position to compare the probable average annual yield of the two districts.

In Longdendale we have 19,000 acres with 50 inches rainfall minus 10 inches "loss."

In Thirlmere we have 11,000 acres with 102 inches rainfall minus 8 inches "loss." Then—

$$19{,}000 \times 40 = 760{,}000$$
$$11{,}000 \times 94 = 1{,}034{,}000.$$

But there are still two other elements to bring into the calculation—viz., the storage capacity of the reservoirs and the length of droughts.

If the storage capacity is small relatively to the watershed area and the rainfall, then a large quantity of water will run to waste, after filling the reservoirs, in times of flood.

When the Longdendale Works were first designed, it was believed that a provision of 34,000 cubic feet of storage per acre of gathering ground would be sufficient; but experience has proved that the quantity ought to be more like 60,000 or 70,000 cubic feet

Even with this greatly increased quantity a certain amount of waste is inevitable.

Then, again, it was assumed that sixty or seventy days would be the duration of the longest droughts; and this has turned out to be nearly 150, a drought in this case meaning the period during which the water in the reservoirs keeps constantly falling, the draught for purposes of "supply" and "compensation" being greater than the inflow from the watershed.

In this respect the Thirlmere district has greatly the advantage of Longdendale.

Droughts.

Mr. Symons stated before the Duke of Richmond's Commission on Water-Supply, in 1869, that the longest recorded drought in the Lake District was sixty-nine days; and this evidence has not been disproved by more recent observations.

In all probability, therefore, if Thirlmere is used as proposed, it will never be drawn down for longer than two months without being replenished.

Then, again, the storage capacity to be provided, instead of being 34,000 cubic feet per acre, is 116,000 cubic feet.

Without going further into figures, it is pretty clear that all the circumstances are very favourable for the collection of a large quantity of water:—

1st. The rainfall is very great;

2nd. The loss by evaporation and absorption is small;

3rd. The droughts are short; and

4th. The storage capacity is large.

We may safely concur with Mr. Bateman's opinion that 50,000,000 gallons may be taken to Manchester after making a fair provision for the discharge of compensation water to the river.

WORKS AT THIRLMERE.

The works required to be done in order to utilise the lake as a storage reservoir are of the most simple character.

It is not intended to take a single drop of water from the existing lake.

The aqueduct conveying the water to Manchester will start from the present level, and the storage will be provided by putting 50 feet of water *above* that level.

This will be effected by building an embankment across the outlet into St. John's Beck, at the north end, which will cause the water to rise until it has attained that height, when the discharge of any surplus will be provided for by the construction of an overflow or waste-weir, delivering the water into the beck below the embankment.

The present area of the lake is 350 acres, and by raising the level it will be increased to 800 acres.

Let me now call your attention to the vast superiority of Thirlmere over Longdendale as a site for obtaining storage, and this, with a little explanation, you will readily realise by a simple comparison of the plans and sections. (See Diagrams No. 1, 2, and 4.)

Remember that in Longdendale from Bottoms Bank to the top of Woodhead Reservoir there is a rise of 344 feet in about $5\frac{1}{2}$ miles, or 64 feet in a mile, and that five embankments, having an aggregate height of 380 feet, have been required to impound 625,000,000 cubic feet, and to create a water area of 460 acres.

Then turn to Thirlmere, and note that for over $2\frac{1}{2}$ miles the bottom of the reservoir (that is, the present surface of Thirlmere) is absolutely level for an area of 350 acres, and that when it is raised, the total rise will be only 50 feet in $3\frac{3}{4}$ miles, or about 14 feet in a mile, and that one 50-feet embankment will impound 1,300,000,000 cubic feet, and create a water area of 800 acres.

Rainfall required to fill Raised Lake.

It will require 32 inches of rainfall running off the watershed area to fill this magnificent reservoir.

Excepting at the embankment and the entrance or "forbay" of the aqueduct—which will be at the south end (see Diagram No. 1)—there will be no artificial works upon the lake.

The water will simply rise 50 feet as it now rises 6 or 8 feet every heavy flood, and its margin will be as much Nature's own line as it is at present.

On Diagram No. 1 you will see exactly the effect of the raising:

the part coloured blue is the existing lake.* Along the east side you will notice that the margin is tame and regular; on the west it is broken up by bays and promontories, and is no doubt exceedingly picturesque.

The most beautiful portion is the lower lake (below the bridges), but this cannot be seen from the public road. In this there is one small island.

Area to be submerged.

The part coloured pink shows the additional area that will be submerged, the two shades of colour marking the margins of successive layers or strata of water 10 feet deep, shown also upon the sections on Diagram No. 2.

All along the east side the new contour will certainly be equally beautiful with the old. On the west it will still be sinuous and irregular, and probably improved by the formation of two islands.

I have put upon the corner of Diagram No. 1 plans of the two lakes on the one inch to a mile scale, for the sake of comparison. I wish I could also have shown you a model on the 25 inches to a mile scale which has been exhibited in the Commons' Committee-room, because from that you could have formed a very good idea of the extent of the intended raising as compared with the giant mountains around.

It is only necessary to state that Helvellyn towers 2,500 feet above the lake to show how insignificant the alteration will be.

The sections on Diagram No. 2 are drawn on a scale of 6 inches to a mile horizontal, and 100 feet to an inch vertical, but below this longitudinal section I have drawn another on a natural scale; that is, having both horizontal and vertical scale the same.

On this scale the 50 feet raising is represented by one-seventeenth of an inch.

* This description refers to the diagrams used at the lecture. Those bound herewith are not coloured, and the 10-feet layers of water referred to below are not shown, the scale being too small. The area to be submerged by the raising of the lake is shaded both on plan and section.

Site of Dam.

Now look again at Diagram No. 2. Fig. 5 is a longitudinal section of the embankments; that is, a section taken along what is intended to be the centre line of the two dams.

The river (St. John's Beck) now runs through the gap on the right. Probably at one time it ran also through the one on the left; and it is even very likely that ages ago its outlet was at a considerably higher level—as high, in fact, as 50 feet above the present surface.

What is now to be done will therefore be a simple restoration.

Across from the base of Raven Crag, on the west, to Great How, on the east, there is a barrier of solid rock nearly closing the valley, which, as seen from the high ground of Round Mount, has much the appearance of an artificial embankment. The summit of this barrier has evidently been exposed in the glacial period to the grinding and rounding action of ice; and there can be little doubt that in a subsequent era the lake was of much the same extent as it is now proposed to make it.

The gap on the right has the rock exposed over its whole surface; the one to the left is filled to a depth of 10 or 12 feet by alluvial deposit, but the rock has been proved by boring below. The mound that rises up between these two gaps is also of solid rock.

In order safely to found the embankments and form a watertight dam it will be necessary only to cut a trench eight to ten feet deep into the rock, for this is very different material from the "millstone grit" of the Longdendale valley.

"The whole of the district is composed of low members of the Cambrian system, called sometimes 'green slates,' having occasional dykes of porphyry and other igneous rocks, and containing some mineral veins."

The rock is dense, compact, and unfissured; any faults that exist will be close faults, practically impervious to water.

Probably a dam of masonry or concrete will be the most appropriate and suitable construction for this district, because it would be difficult to scrape together off the bare surface of the rocks sufficient material for an earth embankment, and the stonework would very speedily be coated with moss and other wall-plants, and become of the grey neutral tone of the surrounding country.

Discharge Tunnel.

Before the dams are commenced, however, the first work would be the formation of another outlet for the river. It would not be convenient, even if the dams were of masonry—and it would be impossible if they were of earth—to allow the water to rise and pass over them during construction.

A tunnel will therefore be driven from the present lake-level right through the rock betwixt the two dams, sufficiently large to pass the heaviest floods into the river below. This being completed, the dams may be proceeded with and carried up to the necessary height.

Waste-Weir.

Simultaneously the waste-weir or overflow will be formed down the west side for the purpose of carrying off the surplus water of floods when the raised lake is full.

In reservoir construction this is frequently a very costly part of the undertaking, requiring to be formed of first-class masonry where the material to work in is unsound rock or earth of any description.

In this case it will only be necessary to put in a level stone cill of suitable length, and then excavate an unlined channel forward to the river, which will thus have the appearance of one of the natural water-courses of the district.

A favourable opportunity will then be taken of partially closing the tunnel by a water-tight masonry bulkhead, and fixing in it the valves for the discharge of the compensation water.

All these operations will be, under such circumstances, easy of accomplishment, and executed at moderate cost.

Cost of Dams.

The expense of all the works in connection with the dams is estimated at about £26,000, just about one-fourth of the cost of *one* of the embankments in Longdendale shown on Diagram No. 4.

Content of Raised Lake.

When raised, the lake will contain above its present surface nearly 1,300,000,000 cubic feet, or 8,000,000,000 gallons.

The rainfall of an average year, or rather the water running off the ground, will be sufficient to fill it nearly three times over in a year if it were drawn down the fifty feet.

This, however, will never be the case, for in order to meet the objections of the opponents to the scheme, the lake is intended to be raised considerably more than would have been necessary, to provide storage enough to tide over the droughts of this district.

Drawing Down of Water.

In the statement prepared by the Thirlmere Defence Association, the following passage occurs :—

"The level of the lake is to be raised on the very lowest estimate thirty-five feet, and this elevation, the engineer tells us, will increase its area from 335 acres—its present extent—to 700. This increased capacity is wanted for storage during the wet winter months, and will be entirely useless unless the reserved water be drawn off in summer; so that in a fine season the lake may be reduced to its present area, and the 365 acres of land previously submerged will be again exposed to view. Just at the time, then, when the valley is visited by strangers from every part of the kingdom, the ever-living green surface of the meadows at the south end of the valley, which, as you descend from Dunmail Raise, form so charming a foreground to the more romantic beauties beyond, will, in such case, be exchanged for a vast expanse of oozy mud and rotting vegetation, whilst a belt of like character will be laid bare round the shores of the lake, and the total extent of this hideous margin will more than equal the area of the remaining water; and this, be it remembered, not in an out-of-the-way place where the deformity might be avoided, but in a valley at the very heart of the Lake District, and traversed by its most frequented road."

If this statement were likely to be verified in the actual result, the charge would no doubt be a serious one, as the beauty of the scenery would inevitably be much impaired.

In several particulars, however, it is satisfactory to know that the amount of disfigurement is greatly overstated :—

First, because the flat marshy meadows at the head of the lake, cut up as they are by straight stone walls, are not generally considered very beautiful.

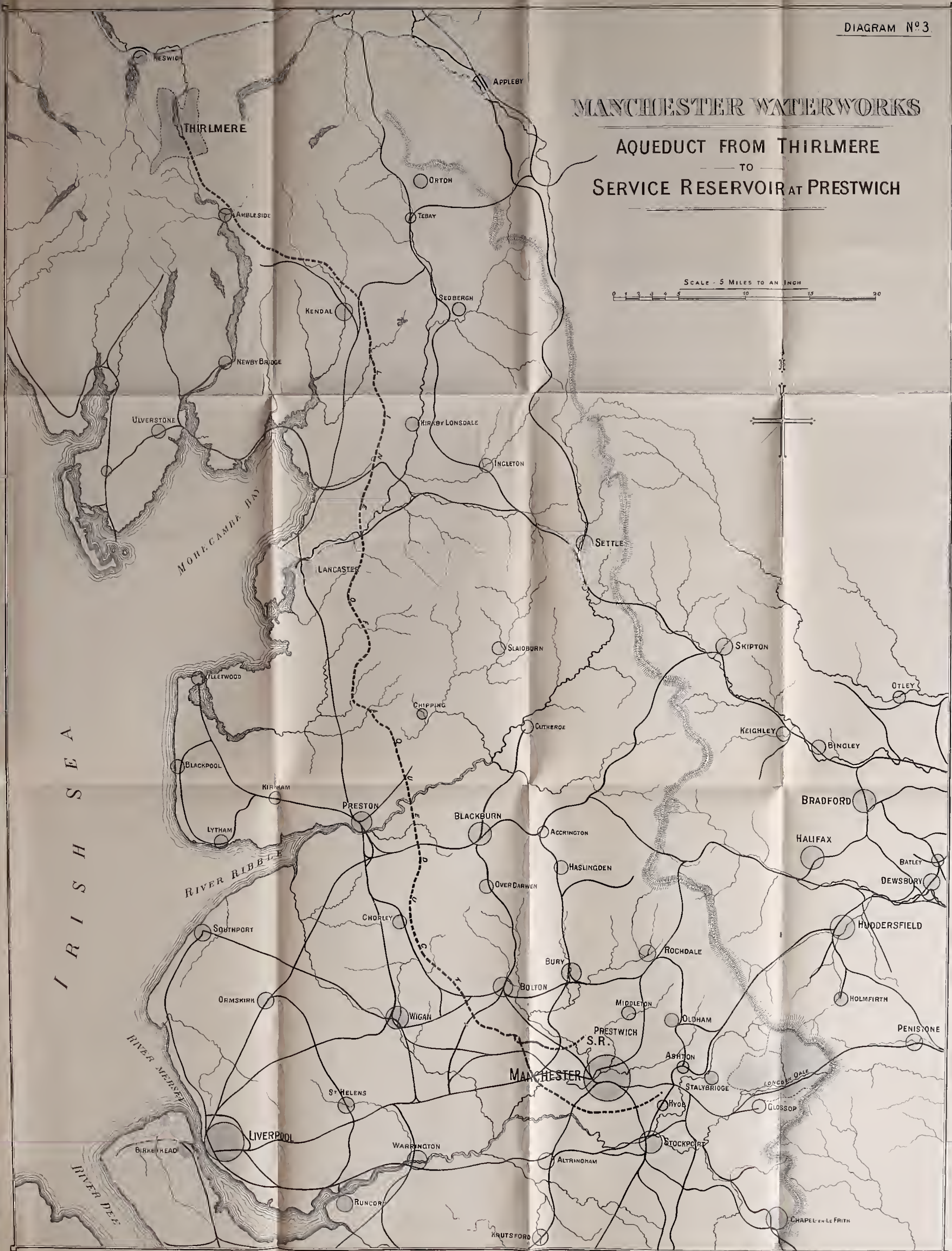


DIAGRAM No 3
MANCHESTER WATERWORKS
AQUEDUCT FROM THIRLMERE
TO
SERVICE RESERVOIR AT PRESTWICH
SCALE - 5 MILES TO AN INCH
0 1 2 3 4 5 10 15 20
KESWICK
THIRLMERE
APPLEBY
ORTON
TEBAY
AMBLESIDE
KENDAL
SEDBERGH
NEWBY BRIDGE
ULVERSTONE
KIRKBY LONSDALE
INGLETON
MORECAMBE BAY
SETTLE
LANCASTER
SLAIDBURN
SKIPTON
FLEETWOOD
CHIPPING
OTLEY
CLITHEROE
KEIGHLEY
BINGLEY
BLACKPOOL
IRISH SEA
KIRKHAM
PRESTON
BRADFORD
BLACKBURN
LYTHAM
ACCRINGTON
HALIFAX
RIVER RIBBLE
HASLINGDEN
BATLEY
OVER DARWEN
DEWSBURY
CHORLEY
SOUTHPORT
HUDDERSFIELD
ROCHDALE
BURY
BOLTON
ORMSKIRK
MIDDLETON
HOLMFIRTH
WIGAN
OLDHAM
PRESTWICH
S.R.
PENISTONE
RIVER MERSEY
ASHTON
MANCHESTER
STALYBRIDGE
LONGDEN DALE
ST HELENS
HYDE
GLOSSOP
LIVERPOOL
BIRKENHEAD
WARRINGTON
STOCKPORT
ALTRINCHAM
RIVER DEE
RUNCORN
CHAPEL-EN-LE FRITH
KNUTSFORD

Second, because the lake will never be drawn down, except in case of accident, so far as to expose anything like an area of 365 acres; and

Third, because the exposed expanse will not be "oozy mud and rotting vegetation," but clean grey shingle.

The following table shows the extent to which the lake—after being raised 50 feet—will be lowered by the withdrawal of instalments of 10 million gallons daily to Manchester, and the discharge of the compensation water ($5\frac{1}{2}$ million gallons).

Quantity withdrawn for Manchester.	Length of Drought.														Time it would take to lower Lake to its present Level.
	If 40 days Lake lowered		If 50 days Lake lowered		If 60 days Lake lowered		If 70 days Lake lowered		If 80 days Lake lowered		If 90 days Lake lowered		If 100 days Lake lowered		
Gallons per day.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Days.
10,000,000	2	10	3	4	3	6	4	2	4	8	5	3	5	10	676
20,000,000	4	3	5	4	6	4	7	5	8	6	9	6	10	9	369
30,000,000	6	2	7	8	9	2	10	10	12	6	14	3	15	10	253
40,000,000	8	2	10	2	12	4	14	7	16	9	19	1	21	7	193
50,000,000	10	0	12	9	15	6	18	4	21	4	24	6	27	8	157

From the above it will be seen that at the end of the longest drought ever registered in the district, viz., 70 days, and when the full quantity of 50 million gallons a day are being taken to Manchester, the lake will be drawn down only 18 feet 4 inches.

If the water had been raised, say only 30 feet, of course the drawing down for similar quantities would have been greater because the area would have been so much less.

Now if you will turn to Diagram No. 1, you will see a dotted line in the shaded portion representing the margin of the lake when the water is drawn down 18 feet 4 inches.

The area thus exposed will be about a third of the 365 acres, as quoted above; and it must be remembered that this amount of drawing down will only happen when the full quantity is being taken to Manchester, and at the end of such a drought as occurs only at intervals of many years.

Then as to the mud and rotting vegetation. No mud is brought

down by the streams; there is no material on the gathering ground capable of forming mud.

The *débris* is merely disintegrated rock.

When the fields in this district are ploughed, a great deal more stone is turned up than soil, in fact the ploughed fields are quite grey in colour.

Now when the land has been covered with water for some months, all vegetation will be destroyed, the scant soil will be washed away by the ripple of the waves, and there will remain a clean grey shingly beach, such as is to be found on the margin of most of the Cumberland lakes.

The strong language used in the Thirlmere Defence Association's pamphlet has no doubt been excited, owing to a misapprehension of the effect of the works, and the fears of its authors will probably have been somewhat allayed by the explanations given in evidence.

The members of the Commons' Committee have apparently not attached much importance to these fears, as they have unanimously passed the preamble of the Bill.

One of the witnesses for the promoters was Mr. William Brodrick Thomas, one of the most eminent landscape gardeners in the country.

He was asked to go down to Thirlmere, to give his opinion as an expert as to whether the raising of the lake would injure its picturesqueness.

Before the Committee he stated that from what he had read and heard of the scheme before his visit, his feelings were rather against it than in favour of it.

In order to enable him to realise the effect of the alteration he caused flags to be planted at the 50 feet level all round the lake, and then carefully surveyed the whole both from the banks and by means of a boat. His deliberate opinion after this careful examination was that the beauty of the scenery would be enhanced.

Such an opinion is very valuable, because it is Mr. Thomas's business to determine how things will look after they have been altered, and from his large experience, this special qualification of realising the effect of altered circumstances he possesses in an exceptional degree.

Mr. Thomas's evidence clearly carried considerable weight with

the Committee, as almost every member asked him several questions after his examination by counsel was completed.

As part of the scheme the Corporation propose to construct a good road along the west side of the lake, to replace a very bad one which now exists.

This road will run along the hill-side, principally in the woods, about 40 feet above the raised water level, and will give tourists an opportunity of visiting the lower lake, and obtaining views of the Helvellyn range, which are not now obtainable. Another road will also be made over the embankment.

The circuit of Thirlmere by means of these roads, either from Grasmere or Keswick, will no doubt become a favourite excursion, partly on account of the grand scenery, and partly on account of the "marvels of engineering skill" to be constructed under the auspices of the Manchester Corporation.

I will venture to predict that, as a rule, visitors will be delighted with the scenery, and, on account of their insignificance, excessively disappointed with the "works."

Before leaving the lake, just a few words as to the "compensation water."

By the Bill, it is proposed to discharge, as compensation to the river, about $5\frac{1}{2}$ million gallons a day, or about 2,000 million gallons a year.

This is equivalent to 9 inches of rainfall on the gathering ground.

The quantity has been objected to by the opponents, on the ground that it is not the usual proportion of the collectable water.

In the manufacturing districts of Lancashire and Yorkshire it has become the practice to give one-third of the water that can be collected on the average of three consecutive dry years, and this works out to something between 6 and 12 inches.

Mr. Bateman contends (and with reason) that such a rule should not be made to apply to a district where the average collectable rainfall of three consecutive dry years will be 80 to 90 inches, instead of 25 to 30.

The amount of compensation ought clearly to be given in relation to the use that is made of the water for mills, &c., at the present time, and in relation also to the dry-weather flow of the streams.

Now on the river betwixt Thirlmere and the Solway at Workington, the mills are comparatively insignificant, and are probably

not adapted to use more than 9 inches of rainfall from the whole watershed above them.

And again in a drought, the quantity of water running down St. John's Beck will probably not average more than *one-fourth* the quantity proposed to be given, and it is not unlikely that the *minimum* flow will not exceed one-tenth of this quantity.

The stream will clearly, therefore, be improved in summer by having its volume increased, and in winter the whole country below will be benefited, both in a pecuniary and sanitary sense, by the diminution of floods consequent upon the storing of the water in enlarged Thirlmere.

Before very shortly describing the aqueduct, I must explain that I have talked of the quantity of water obtainable on the *average of years* from the gathering grounds, in order to simplify the comparison betwixt Longdendale and Thirlmere, but I must guard against misapprehension by adding that we cannot deal with averages, in designing waterworks.

The only safe basis for all calculations is to assume that the maximum demand for water will take place just when the sources of supply are at the lowest.

Any works constructed on a foundation of average yield, and average requirement, would sooner or later become a complete failure.

Aqueduct.

The aqueduct will commence, as I have before stated, at the south-east corner of the lake, and at such a level that the surface of the water running in it at the entrance will be about 531 feet above Ordnance datum.

The water will be delivered into the Prestwich service reservoirs—96 miles distant—at a height of 353 feet above datum, and will therefore have a fall in this length of 178 feet.

Now imagine a straight line drawn from 531 at Thirlmere to 353 at Prestwich. This would represent the gradient line or inclination betwixt the two points.

Although this line will be straight in the vertical plane, you must understand that it cannot be a straight line *in plan*, but must be set out so as to follow a course which will facilitate the construction of the aqueduct in a safe and economical manner.

I remember when I went out many years ago to assist in the making of one of the first railways in Brazil, the prevalent idea among the natives was that the line would be straight and level from one end to the other. They had no notion that it would wind about among the valleys, rising and falling over the hills, and so find an easy track from one point to another.

Possibly some of you may have formed some such an idea of the aqueduct from Thirlmere to Manchester.

If you look at Diagram No. 3, upon which the aqueduct is shown by a strong dotted line, you will see what its actual course is intended to be.

This line has of course been selected after a careful study of the ground, having been primarily laid out upon the 6-inch Ordnance maps which I have before referred to.

From these a very close approximation to the whole length could be arrived at, and then by dividing the fall of 178 feet into this length the gradient or rate of inclination would be ascertained.

It would have been impossible to put upon the wall an intelligible section to correspond with the plan, Diagram No. 3, because the scale is much too small.

Upon the table there is, however, a copy of the Parliamentary plans, containing the section on a scale of 6 inches to a mile horizontal, and 100 feet to an inch vertical.*

An examination of this will show that even after the best possible line has been chosen, the works are in many places very heavy.

For instance, in the first 22 miles after leaving Thirlmere, the aqueduct passes through the Lake District to near Kendal, and in this portion there are 17 tunnels having an aggregate length of 14,000 yards; 7 syphons having an aggregate length of 9,000 yards; and the remainder, 15,700 yards, is what is known as "cut and cover."

The longest tunnel is 5,225 yards, and the greatest depth of a tunnel below the surface 660 feet. The longest syphon 5,720 yards, and the maximum depth below the gradient line 305 feet.

Commencing from the lake, the aqueduct goes right into "tunnel" at once under the slope of Helvellyn, and continues alongside the public road,—but 200 feet below it,—until it comes

* Used at lecture.

again to daylight about a mile south of the summit of Dunmail Raise.

This tunnel will be a simple excavation in the rock about 7 feet square, trimmed off pretty true inside but probably left entirely unlined, because the compact and water-tight nature of the material renders this unnecessary.

Emerging from the tunnel the aqueduct will then skirt or "contour" the hill-side on the ruling gradient of 20 inches to a mile, being located so that it may be built in a trench and the ground replaced over it.

This is called "cut and cover" work. An open trench with vertical sides is excavated in the rock about 7 feet wide, but broader at the top, to allow of an arch springing from the two sides to form the "cover," the earth being filled in over the arch and the soil replaced.

This is the cheapest mode of construction that can be adopted, and therefore the contour line is followed as far as practicable throughout.

Every now and then a deep valley is met with which it is cheaper to cross "shortly" in another way, and in the same manner a great hill which it is better to pierce through than to go round.

The tunnels and the "cut and cover" parts of the aqueduct will be made large enough to convey 50 million gallons in 24 hours.

To do this, the depth of water will be about 5 feet 6 inches, and, of course, the work will never be under greater pressure than this depth.

In the valleys—that is, wherever the ground drops below the gradient line—iron pipes will be laid. The Romans would have built aqueducts on several tiers of arches up to the gradient line, because they could not cast large pipes.

In examining the remains of the Claudian Aqueduct, near Naples, I was surprised to find that in several places it was laid at a great depth below the ground, and I was some time before I found a satisfactory reason for this, but at last I concluded that the excessive depth of cutting was adopted in order to avoid a very high aqueduct in another place, which might be endangered by its proximity to Vesuvius.

Here it is proposed to lay cast-iron pipes forty inches in diameter, which will be sufficiently large to convey 10,cco,000 gallons of water per day.

Simultaneously with the construction of the rest of the aqueduct, *one* of these forty-inch pipes will be laid across each valley, and when the demand has sufficiently increased, a second, third, and so on, until five parallel rows of pipes have been laid capable of discharging together 50,000,000 gallons a day.

This plan will be adopted from motives of economy.

Such pipes may be cast strong enough to bear many times the pressure that will be put upon them. In the first twenty-two miles the greatest pressure will be 305 feet, viz., in the crossing of the valley of the rivers Sprint and Mint, near Kendal; but at the crossing of the river Lune, near Lancaster, the pressure upon the pipes will be about 416 feet, or equal to about 200 lbs. on the square inch.

These pipes will be laid under-ground in the ordinary manner, and will not be visible except at the crossing of the more important streams, and rivers like the Lune, Ribble, &c. There bridges will be built of two or three openings, as the case may be, and the pipes laid over them.

There will be nothing exceptionally difficult in the construction of this aqueduct on any part of its course.

By the Thirlmere Defence Association it has been described in language of a most misleading character. Thus on page 8 of the pamphlet they say:—

"The aqueduct, be it remembered, is to convey from 40 to 50 million gallons of water daily, and will run for seven or eight miles on the hills *impending over* a thickly-peopled valley, on the slopes of which are situated a succession of residential properties, which, for value and beauty, are scarcely to be equalled in this or any other country. At some 300 to 400 feet above all this, the enormous volume of water will *hang suspended.* Engineers may look coolly at such risks, but non-professional men will think that absolute security from such casualties of rain and frost as are sure to occur in the course of years, is an impossibility; and it is quite certain that to secure reasonable safety, under ordinary circumstances, in passing over our rugged hills, with their bold rocky projections and scanty soil, works will be needed which will utterly ruin the beauty of some of the fairest spots.

"The streams, too, which in their natural course form one of the most charming features of the landscape, will be cut off from their

sources, and, whatever be done with the larger becks, the natural drainage of the whole country-side will necessarily be disturbed and diverted for security to the aqueduct and its foundations."

From my description you will be able to form an opinion as to the propriety of this language.

It is certain that no harm can come from the tunnels ; they will be excavated in the solid rock, and will never be even filled with water.

The "cut and cover" work will be equally secure, because it will be placed in the solid hill-sides.

The streams will certainly not be cut off from their sources (whatever that may mean), nor will they be interfered with in the slightest degree. In some cases the iron pipes will be laid right under their beds, and in others they will be spanned by bridges of suitable character and ample dimensions. In neither case will the flow of the streams be disturbed or interrupted.

On Thursday, the 28th of March, the Commons' Committee passed the preamble of the Bill, after a hearing extending over sixteen days ; and, in doing so, they imposed the condition on the promoters that they should construct the works through the ornamental estates of the Lake District in such a way as to meet the reasonable approval of the owners.

This the Manchester Corporation will, of course, be very glad to do.

MANCHESTER WATERWO

EXISTING RESERVOIRS ON THE RIVER ETHEROW

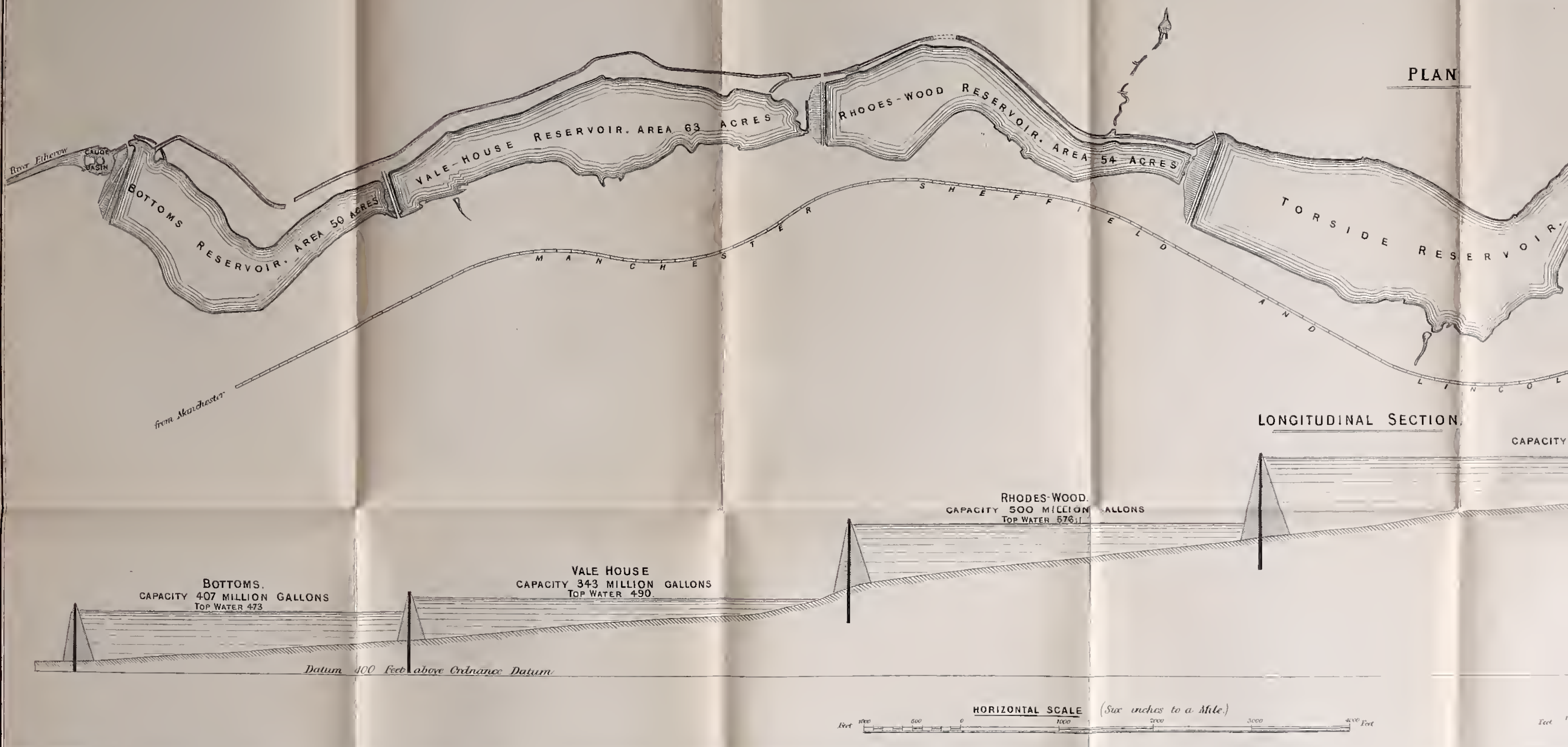
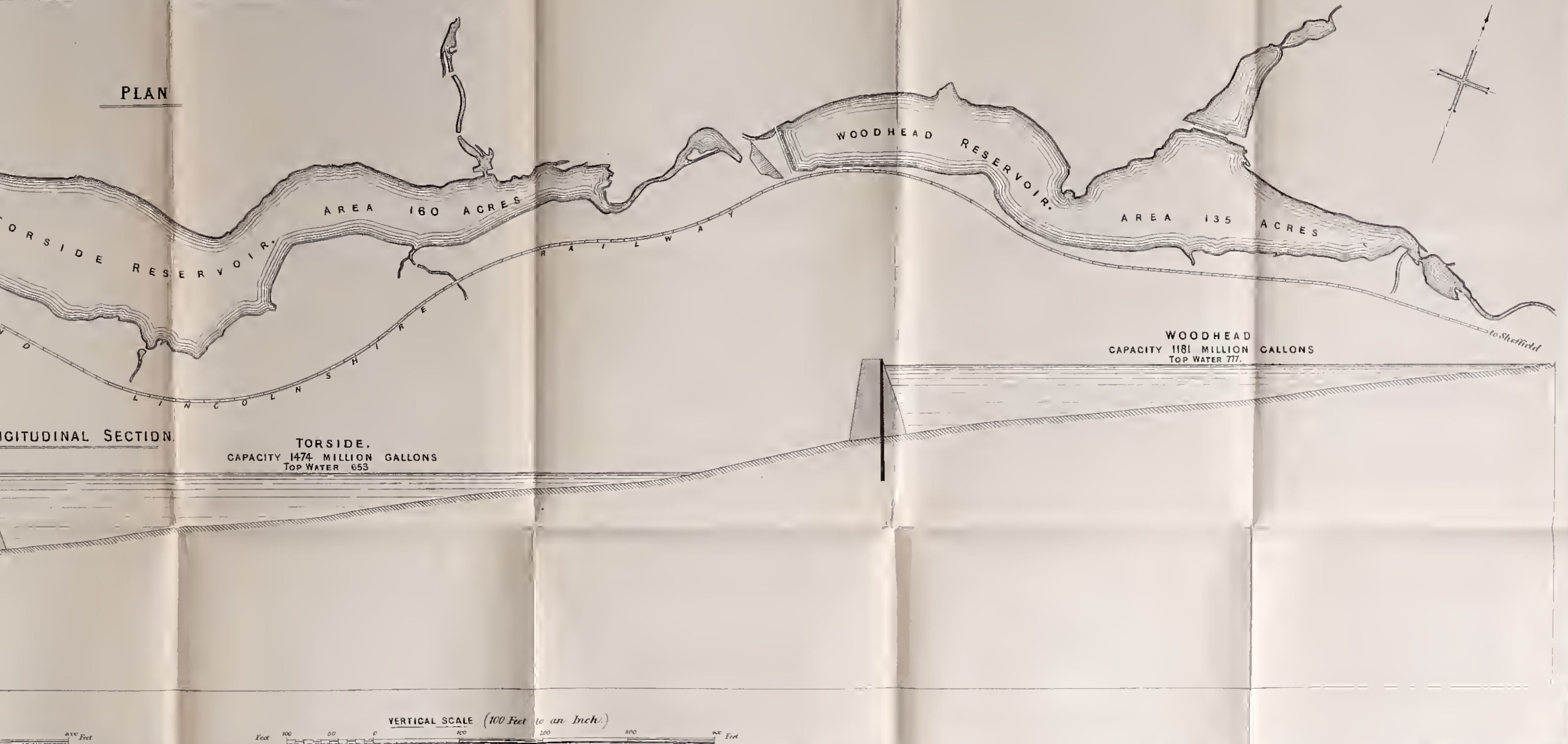


DIAGRAM Nº 4.

CHESTER WATERWORKS

OIRS ON THE RIVER ETHEROW IN LONGDEN-DALE



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